**ENCLOSURE 6**

PRAIRIE ISLAND NUCLEAR GENERATING PLANT

SUPPORTING ENGINEERING EVALAUTIONS

EC 16275

44 Pages Follow

Xcel Energy

# EC-0441 EC Closeout Package Report (Rev. 3)

**Report Date: 06/11/2010**

# EC Number: 0000016275 Revision: 000

## Engineering Change

| | | | | | |
|---|---|---|---|---|---|
| **EC Number** : | 0000016275 | 000 | **Facility** | : | PI |
| **Status/Date** : | CLOSED | 06/10/2010 | **Type/Sub-type** | : | EVAL / |

**EC Title:** EFFECTS OF PIPE WHIP INTERACTIONS FOR VARIOUS PIPE COMBINATIONS FOR INTERNAL FLOODING SDP

**Mod Nbr:** **KW1:** **KW2:** **KW3:** **KW4:** **KW5:**

| | | | | | |
|---|---|---|---|---|---|
| **Master EC** | : | **Work Group** | : | **Temporary** | : |
| **Outage** | : | **Alert Group** | : E-REG PROG | **Aprd Req. Dt.** | : 07/01/2010 |
| **WO Required** | : N | **Image Addr** | : | **Exp Insvc Date** | : |
| **Adv Wk Appvd** | : | **Alt Ref.** | : | **Expires On** | : |
| **Auto-Advance** | : | **Priority** | : | **Auto-Asbuild** | : |
| **Caveat Outst** | : | **Resp Engr** | : PTTD06 | | |

## Units and Systems

| Facility | Unit | System | System Description |
|---|---|---|---|
| PI | 0 | OTH | OTHER |

## Attributes

| Attribute Name | Value | Updated By | Last Updated | Notes |
|---|---|---|---|---|
| SCRN NO | NA | PTTD06 | 06/10/2010 | This evaluation does not support design basis. |
| SIMULATOR | | | | |
| SYSTEM HEALTH | | | | |
| EVAL NO | | | | |
| PORC DTE | | | | |
| PRIORITY RANKING | | | | |

Xcel Energy

# EC-0441 EC Closeout Package Report (Rev. 3)

**Report Date: 06/11/2010**

## Topic Notes

| Topic | Notes |
|---|---|
| DESCRIPTION | See Attached in sharepoint. |
| JUSTIFICATION | See Attached in sharepoint. |
| REVIEWER COMMENTS | Owners comments:<br>14" Table<br>Interaction 186 should be interaction 188. Tthe remainder of data stay the same for the line item.<br><br>16" Table<br>One interaction needs to be added (it will be bounded by interaction 15)<br><br>No<br>115 Unit<br>2 Elev<br>695 Row<br>B Column<br>14 HE Line<br>20-2CD-7 [40] NPS<br>20 ID<br>19.25 Wall Thickness<br>0.375 Area (In^2)291 Crack Size<br>1.80 Target ID<br>16-2CL-9 [32] Sch<br>30 Thickness<br>0.375 Distance<br>6"<br><br>Operating Pressure of 20-2CD-7 = 420 psig<br><br>24" Table<br>Interaction 20a needs to be added. The data is identical to Interaction 20.<br><br>The above comments were incorporated.<br><br>Interaction 151 was requested to be assessed. However, the results were not coming out favorably. AES was requested not to pursue this piping interaction further as it was acknowledged that the interaction was not possible based upon field walkdowns. |

## Cross References

| XRef | Number | Sub | Status | Date | Reference Description |
|---|---|---|---|---|---|
| AR | 01178236 | | APPROVED | 04/15/2009 | No HELB flooding calculation for Turbine Building |

## Affected Documents

## Milestone

| Milestone | Date | ID | Name | Req By |
|---|---|---|---|---|
| APPROVED BY | 06/10/2010 | BRSM05 | Brossart, Mark A | APPROVED |

Xcel Energy

# EC-0441 EC Closeout Package Report (Rev. 3)

**Report Date: 06/11/2010**

## Milestone

| Milestone | Date | ID | Name | Req By |
|---|---|---|---|---|
| **Notes:** Suitability review performed by a qualified individual and attached in Sharpoint. Comments listed in Topic Notes were incorporated. EC is approved. | | | | |
| CLOSE | 06/10/2010 | LDWHIP01 | Whipple, Linda D | CLOSED |
| **Notes:** | | | | |
| PRE JOB BRIEF | 06/10/2010 | PTTD06 | Potter, David J | |
| **Notes:** | | | | |
| PREPARED (EVL) | 06/10/2010 | PTTD06 | Potter, David J | H/APPR |
| **Notes:** | | | | |

## Document References

| Facilty | Doc-Type | Sub-Type | Doc # | Sheet | Rev | Minor Rev | Date |
|---|---|---|---|---|---|---|---|
| PI | EC | | 0000016275 | | 000 | | 06/10/2010 |

| Xcel Energy | **External Design Document Suitability Review Checklist** |
|---|---|

**External Design Document Being Reviewed:Engineering Evaluation**

Title: **Technical Backup for Turbine Building HELB Screening Evaluation**

Number: PI-996-83-S01 Rev: 1 Date: 6/10/10

**This design document was received from:**

Organization Name: AES PO or DIA Reference: EC16275

The purpose of the suitability review is to ensure that a calculation, analysis or other design document provided by an External Design Organization complies with the conditions of the purchase order and/or Design Interface Agreement (DIA) and is appropriate for its intended use. The suitability review does not serve as an independent verification. Independent verification of the design document supplied by the External Design Organization should be evident in the document, if required.

The reviewer should use the criteria below as a guide to assess the overall quality, completeness and usefulness of the design document. The reviewer is not required to check calculations in detail.

## REVIEW

| | | Reviewed | N/A |
|---|---|---|---|
| 1. | Design inputs correspond to those that were transmitted to the External Design Organization. | ☒ | ☐ |
| 2. | Assumptions are described and reasonable. | ☒ | ☐ |
| 3. | Applicable codes, standards and regulations are identified and met. | ☒ | ☐ |
| 4. | Applicable construction and operating experience is considered. | ☒ | ☐ |
| 5. | Applicable structure(s), system(s), and component(s) are listed. | ☒ | ☐ |
| 6. | Formulae and equations are documented. Unusual symbols are defined. | ☒ | ☐ |
| 7. | Acceptance criteria are identified, adequate and satisfied. | ☒ | ☐ |
| 8. | Results are reasonable compared to inputs. | ☒ | ☐ |
| 9. | Source documents are referenced. | ☒ | ☐ |
| 10. | The document is appropriate for its intended use. | ☒ | ☐ |
| 11. | The document complies with the terms of the Purchase Order and/or DIA. | ☒ | ☐ |
| 12. | Inputs, assumptions, outputs, etc. which could affect plant operation are enforced by adequate procedural controls. List any affected procedures. | ☐ | ☒ |
| 13. | Plant impact has been identified and either implemented or controlled. (e.g., For piping analyses, the piping and support database is updated or a tracking item has been initiated.) | ☐ | ☒ |
| 14. | Design and Operational Margin have been considered and documented. | ☐ | ☒ |

Completed by: David Potter [signature] Date: 6/10/2010

Form retained in accordance with record retention schedule identified in FP-G-RM-01.

| | |
|---|---|
| **Calculation Number:** | PI-996-83-S01 |
| **Calculation Title:** | Technical Backup for Turbine Building HELB Screening Evaluation |
| **Client:** XCEL Energy | **Station:** PINGP |
| **Project Number:** PI-996-83 | **Unit(s):** |
| **Project Title:** | PRA HELB Screening |

**Safety Related** Yes ☐ No ☒

| Revision | Affected Pages | Revision Description | Approval Signature / Date | Signature / Initials of Preparers & Reviewers |
|---|---|---|---|---|
| 0 | All | Initial Issue | A.V. Setlur | **Prepared by:** David DeGrush **Reviewed by:** Olof Andersson |
| 1 | All | Piping interaction tables and associated references revised. | A.V. Setlur 6/10/2010 | **Prepared by:** David DeGrush **Reviewed by:** Olof Andersson |

REVIEWER'S CHECKLIST FOR DESIGN CALCULATIONS SHEET 1 of 2

**STATION:** PINGP **NUCLEAR SAFETY RELATED:** YES ☐ NO ☒

**PROJECT NO:** PI-996- 83 **CLIENT:** NMC, LLC

**CALCULATION TITLE:** Technical Backup for Turbine Building HELB Screening Evaluation

**CALC. NO:** PI-996-83-S01 **CALC. REV. NO:** 1

INDICATE THE DESIGN INPUT DOCUMENTS USED:

| TYPE OF DOCUMENT | DOCUMENT ID, REV AND/OR DATE | YES | N/A | COMMENT |
|---|---|---|---|---|
| **1. General Design Basis** | Ref. 1 - 11 | X | | |
| **2. System Description** | | | X | |
| **3. Design information package from related equipment vendor** | | | X | |
| **4. Electrical Discipline Input** | | | X | |
| **5. Mechanical Discipline Input** | | | X | |
| **6. Control Systems Discipline Input** | | | X | |
| **7. Structural Discipline Input** | | | X | |
| **8. Specifications** | | | X | |
| **9. Vendor Drawings** | | | X | |
| **10. Design Standards** | Ref. 9 | X | | |
| **11. Client Standards** | | | X | |
| **12. Checked Calculations** | Ref. 1, 7 | X | | |
| **13. Other (specify)** | | | X | |

PREPARER'S SIGNATURE: [signature] D. DeGrush DATE: 6/10/2010

REVIEWER'S SIGNATURE: [signature] O. Andersson DATE: 6/10/2010

APPROVER'S SIGNATURE: [signature] A.V. Setlur DATE : 6/10/2010

REVIEWER'S CHECKLIST FOR DESIGN CALCULATIONS — SHEET 2 of 2

PROJECT NO: PI-996-83
CALC. NO: PI-996-83-S01

| REVIEWER TO COMPLETE THE FOLLOWING ITEMS: | YES | NO | N/A | COMMENT |
|---|---|---|---|---|
| **1. Has the purpose of the calculation been clearly stated?** | X | | | |
| **2. Have the applicable codes, standards and regulatory requirements been:** | | | | |
| **A. Properly Identified?** | X | | | |
| **B. Properly Applied?** | X | | | |
| **3. Were the inputs correctly selected and used?** | X | | | |
| **4. A. Was Design Input Log used?** | | | X | |
| **B. If 4A is No, provide Manager's signature in Comment column to signify approval of Design Input Documents used in the calculation.** | | | | (signature) |
| **5. Are necessary assumptions adequately stated?** | X | | | |
| **6. Are the assumptions reasonable?** | X | | | |
| **7. Was the calculation methodology appropriate?** | X | | | |
| **8. Are symbols and abbreviations adequately identified?** | X | | | |
| **9. Are the calculations:** | | | | |
| **A. Neat?** | X | | | |
| **B. Legible?** | X | | | |
| **C. Easy to follow?** | X | | | |
| **D. Presented in logical order?** | X | | | |
| **E. Prepared in proper format?** | X | | | |
| **10. Is the output reasonable compared to the inputs?** | X | | | **Reviewed by Detailed Check** |
| **11. If a computer program was used:** | | | | |
| **A. Is the program listed on the ASL and has the SRN been reviewed for any program use limitations?** | | | X | |
| **B. Have existing user notices and/or error reports for the production version been reviewed as appropriate?** | | | X | |
| **C. Were codes properly verified?** | | | X | |
| **D. Were they appropriate for the application?** | X | | | |
| **E. Were they correctly used:** | X | | | |
| **F. Was data input correct?** | X | | | |
| **G. Is the computer program and revision identified?** | X | | | **LS-DYNA** |

**TABLE OF CONTENTS**

**Section** **Page**

## 1.0 Purpose/Objective

The purpose of this calculation is to perform analysis of pipe-on-pipe impact interactions using finite element simulation. The objective is to quantify the effect of impact of the projectile pipe on a target pipe. The anaylsis will evaluate the impact of specific postulated interactions at the Prairie Island Nuclear Generating Plant (PINGP).

## 2.0 Methodology

Analytical models of two pipe interactions (collisions) are prepared using the Finite Element Simulation code LS-DYNA. The models were comprised of a projectile or moving pipe and a stationary Target Pipe. The physical scenario being analyzed is a postulated catastropic failure occurring in a pressurized piping system producing a projectile pipe which ultimately impacts a stationary or target pipe. The damaged caused by the projectile pipe to the target pipe is evaluated using the finite element code.

The analyses are performed on actual pipe to pipe interactions pairs identified via plant walkdown at PINGP. Engineering evaluations using key parameters identified the specific bounding interaction pairs for each target pipe size. These bounding interactions were modeled to determine the extent of the damage caused by a postulated collision. If the resulting damage for these limiting cases is shown to be acceptable then any damage resulting from the other interactions can be assumed to fall within acceptable limits.

This calculation is classified as Non-Safety Related since it does not result in a design document. The inputs were based upon reasonable and, where possible, conservative values which produced generally conservative results.

**Software**

MathCad software is used to generate this calculation. All MathCad calculations are independently verified for accuracy and correctness as if they were manually generated.

LS-DYNA is used to analyze the pipe to pipe interactions. LS-DYNA is a general purpose explicit/implicit finite element code used to analyze the nonlinear dynamic response of three-dimensional and two-dimensional inelastic structures. Its fully automated contact analysis capability and error checking features have enable users in various industries worldwide to successfully solve many complex crash, forming and other problems. Previously LS-DYNA has been used successfully to analytically model actual experimental pipe to pipe interactions (Ref. 6) which makes it an ideal tool for this analysis. LS-DYNA is not on the AES Approved Software List but it has been used extensively in the industry for non-linear analyses. As such its use is acceptable for this non-safety related application.

## 3.0 Acceptance Criteria

This analysis will be utilized to provide technical backup to support an evaluation which attempts to screen postulated HELB piping interactions within the Turbine Building. The interactions will be screened as those which could significantly contribute to flooding and those that will not. Previous Probabalistic Risk Assessment (PRA) has concluded that leakage flows within the turbine building less than 5000 gpm do not pose a significant threat to plant design basis operation (Ref. 1).

Analysis has shown that 5000 gpm would exceed the expected flowrate through a 4" diameter pipe at system operating pressures of approximately 100 psig which is roughly that of a service water or fire protection system (Ref. 2). The cross sectional flow area of a 4" pipe is approximately 12.7 $in^2$. Therefore a non-threatening pipe interaction will be that considered to cause no more than a 12.7 $in^2$ opening in the target pipe.

## 4.0 Assumptions

1. Only orthogonal perpendicular pipe interactions are considered due to their bounding nature based upon previous testing and analysis. (Ref. 5). Any departure from perpendicularity between the plane of motion of the projectile pipe and the axis of the target pipe would have resulted in a lesser component of the maximum impact force between the pipes.

2. A conservative length of 15 ft is arbitrarily chosen for the projectile pipe to maximize impact forces. The longer the projectile pipe the larger the moment formed about the rotation hinge and thus the greater the impact force. Based upon typical piping geometries, support spacing and general clearances within the plant it is not reasonable to assume projectile pipe lengths longer than 15 ft could occur and move freely without interference from other structures.

3. The theoretical impact point on the projectile pipe is chosen as 10 ft from the fixed base to maximize imparted energy to the target pipe. Previous testing has shown that maximum damage will occur when the impact occurs from 50 to 75% length of the projectile pipe from the hinge Ref.(6). In the event that the plastic hinge forms away from the base the impact zone should fall within this range on the Projectile Pipe.

4. The impact point on the Target pipe is conservatively chosen at the midpoint of the span which maximizes the imparted forces to the pipe. (Ref. 5)

5. The intact end of the projectile pipe is conservatively modeled as rigidly supported (fixed) to maximize impact forces to the Target Pipe. A lesser boundary condition would allow the intact end to deflect or move away from the projected impact and thus reducing the severity of the impact.

6. The blowdown force is assumed to always act perpendicular to the axis of the Projectile pipe. This will maximize the rotational moment of the Projectile pipe, increasing the angular velocity and maximizing the impact force.

7. The length of the Target pipe is reasonably chosen as 1/2 the recommended maximum spacing between piping supports as specified in ASME B31.1 piping code, Table 121.1.4.(Ref. 9) Piping support spacing can vary somewhat throughout the plant and between plants but this is a reasonable input based upon actual field installations.

8. Both pipes are modeled as filled with water. The greater mass will increase the impact energy and maximize the impact result.

9. Material properties for A106 Grade B Carbon Steel are assumed for both pipes.

10. The identical True Stress-Strain curve at elevated temperature is used for both pipes which is conservative due to the fact that the Target pipe is actually at lower temperature which would increase the material strength of this pipe.

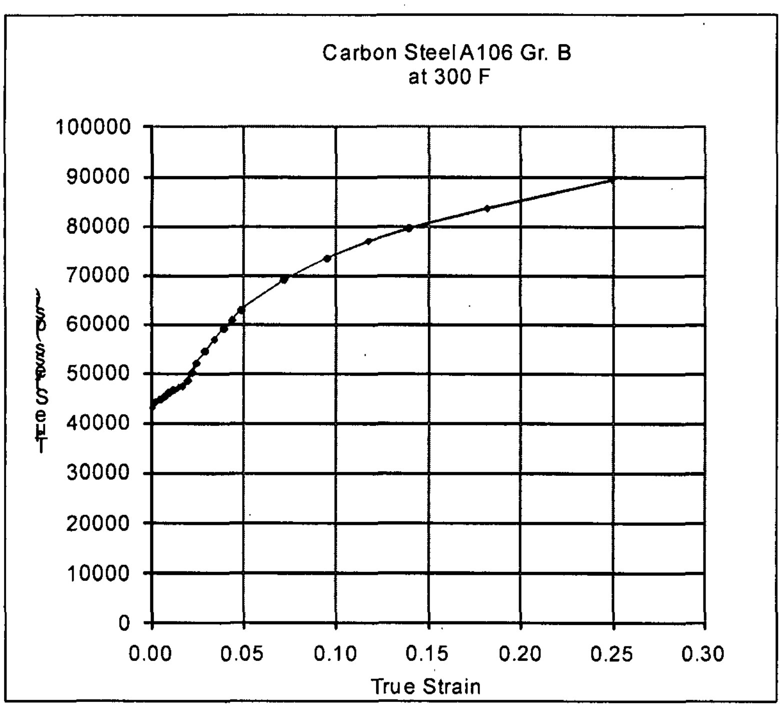
11. The internal pressure in both pipes is conservatively assumed to be atmospheric.

12. Failure will occur at 25% Strain. (Ref. 8)

**5.0 Design Inputs**

**5.1 Material Properties**

The following true stress-strain curve is used for both pipes (Ref 3).




| Eng Strain | Eng. Stress | True strain | True Stress |
|---|---|---|---|
| 0.0010 | 4.29E+04 | 0.0010 | 42965 |
| 0.0020 | 4.39E+04 | 0.0020 | 44023 |
| 0.0025 | 4.42E+04 | 0.0025 | 44326 |
| 0.0050 | 4.45E+04 | 0.0050 | 44766 |
| 0.0075 | 4.49E+04 | 0.0075 | 45247 |
| 0.0100 | 4.56E+04 | 0.0100 | 46008 |
| 0.0125 | 4.60E+04 | 0.0124 | 46585 |
| 0.0150 | 4.64E+04 | 0.0149 | 47053 |
| 0.0175 | 4.66E+04 | 0.0173 | 47374 |
| 0.0200 | 4.75E+04 | 0.0198 | 48427 |
| 0.0225 | 4.91E+04 | 0.0223 | 50232 |
| 0.0250 | 5.07E+04 | 0.0247 | 51951 |
| 0.0300 | 5.29E+04 | 0.0296 | 54471 |
| 0.0350 | 5.49E+04 | 0.0344 | 56822 |
| 0.0400 | 5.67E+04 | 0.0392 | 59002 |
| 0.0450 | 5.82E+04 | 0.0440 | 60819 |
| 0.0500 | 5.98E+04 | 0.0488 | 62746 |
| 0.0750 | 6.42E+04 | 0.0723 | 68969 |
| 0.1000 | 6.67E+04 | 0.0953 | 73395 |
| 0.1250 | 6.85E+04 | 0.1178 | 77023 |
| 0.1500 | 6.92E+04 | 0.1398 | 79578 |
| 0.2000 | 6.97E+04 | 0.1823 | 83587 |
| 0.2840 | 6.97E+04 | 0.2500 | 89438 |

Density for Carbon Steel per Reference [23] : $\rho_{CS} := \mathbf{0.283} \frac{lbf}{in^3}$

### 5.2 Pipe Properties

Target Pipe sizes considered in this evaluation are as follows (Ref. 7)

14 in Sch.XS, 14 in OD, 0.5 in wall thickness,
16 in Sch 30, 16 in. OD, 0.375 in wall thickness,
24 in Sch 20, 24 in. OD, 0.375 in wall thickness,

Projectile Pipe sizes considered (Ref. 7)

8 in Sch 80, 8.625 in OD, 0.5 in wall thickness,
12in Std Sch., 12.75 in OD, 0.375 in wall thickness,
16 in Sch 30 (data given above for Target Pipe)
20 in Sch 20, 20 in OD, 0.375 in wall thickness,

Target Pipe spans: 1/2 suggested max. span in ASME B31.1, Table 121.1.4 (Ref. 9)

14" pipe = 12.5 ft
16" pipe = 13.5 ft
24" pipe = 16 ft

Six bounding pipe interaction cases are identified in Section 6.1

5. Projectile Pipe Parameters for Interaction Pairs (Ref. 7)

Case 1 - Interaction 186/190
Case 2 - Interaction 191
Case 3 - Interaction 15
Case 4 - Interaction 19/109
Case 5 - Interaction 20/123
Case 6 - Interaction 48

Outer Diameter

$$D_{p.o} := \begin{pmatrix} 8.625 \\ 12.75 \\ 16 \\ 20 \\ 16 \\ 20 \end{pmatrix} in$$

Wall Thickness

$$t_p := \begin{pmatrix} 0.500 \\ 0.375 \\ 0.375 \\ 0.375 \\ 0.375 \\ 0.375 \end{pmatrix} in$$

Inner Diameter $D_{p.i} := D_{p.o} - 2t_p$ $D_{p.i} = \begin{pmatrix} 7.625 \\ 12.000 \\ 15.250 \\ 19.250 \\ 15.250 \\ 19.250 \end{pmatrix} \cdot in$

Operating Pressure in Projectile Pipe (Ref. 7) $P_p := \begin{pmatrix} 685 \\ 420 \\ 420 \\ 420 \\ 420 \\ 420 \end{pmatrix} psi$

Mass of Pipe (Ref. 11) $m_{p.p} := \begin{pmatrix} 43.4 \\ 49.6 \\ 62.6 \\ 78.6 \\ 62.6 \\ 78.6 \end{pmatrix} \frac{lb}{ft}$

Mass of Water Inside Pipe (Ref. 11) $m_{p.w} := \begin{pmatrix} 19.8 \\ 49.0 \\ 79.1 \\ 125.7 \\ 79.1 \\ 125.7 \end{pmatrix} \frac{lb}{ft}$

Total Mass of Pipe $m_p := m_{p.w} + m_{p.p}$ $m_p = \begin{pmatrix} 63.2 \\ 98.6 \\ 141.7 \\ 204.3 \\ 141.7 \\ 204.3 \end{pmatrix} \cdot \frac{lb}{ft}$

Inner Cross-Sectional Area of Pipe $A_{p.I} := \overrightarrow{\frac{\pi \cdot D_{p.i}^{2}}{4}}$ $A_{p.I} = \begin{pmatrix} 45.7 \\ 113.1 \\ 182.7 \\ 291.0 \\ 182.7 \\ 291.0 \end{pmatrix} \cdot in^2$

Length of Projectile Pipe (Assumption #2) $L_p := 15ft$

Theoretical Position of Impact on Projectile Pipe from hinge assuming Ideal hinge (Assumption #3) $l_p := 10ft$

Target Pipe Parameters for specific interaction pairs (Ref. 7)

Outer Diameter $D_{t.o} := \begin{pmatrix} 14 \\ 14 \\ 16 \\ 16 \\ 24 \\ 24 \end{pmatrix} in$

Wall Thickness $t_t := \begin{pmatrix} 0.500 \\ 0.500 \\ 0.375 \\ 0.375 \\ 0.375 \\ 0.375 \end{pmatrix} in$

Inner Diameter $D_{t.i} := D_{t.o} - 2t_t$ $D_{t.i} = \begin{pmatrix} 13.00 \\ 13.00 \\ 15.25 \\ 15.25 \\ 23.25 \\ 23.25 \end{pmatrix} \cdot in$

Mass of Pipe (Ref. 11)

$$m_{t.p} := \begin{pmatrix} 72.1 \\ 72.1 \\ 62.6 \\ 62.6 \\ 94.6 \\ 94.6 \end{pmatrix} \frac{lb}{ft}$$

Mass of Water Inside Pipe (Ref. 11)

$$m_{t.w} := \begin{pmatrix} 57.5 \\ 57.5 \\ 79.1 \\ 79.1 \\ 184.0 \\ 184.0 \end{pmatrix} \frac{lb}{ft}$$

Total Mass of Pipe

$$m_t := m_{t.w} + m_{t.p} \qquad m_t = \begin{pmatrix} 129.6 \\ 129.6 \\ 141.7 \\ 141.7 \\ 278.6 \\ 278.6 \end{pmatrix} \cdot \frac{lb}{ft}$$

Inner Cross-Sectional Area of Pipe

$$A_{t.I} := \overrightarrow{\frac{\pi \cdot D_{t.i}^{2}}{4}} \qquad A_{t.I} = \begin{pmatrix} 132.7 \\ 132.7 \\ 182.7 \\ 182.7 \\ 424.6 \\ 424.6 \end{pmatrix} \cdot in^2$$

## 6.0 ANALYSIS

### 6.1 Modeling Discussion

The model considers only orthogonal / perpendicular pipe interactions based upon previous studies (Ref. 5). Both pipes were modeled as cylinders containing water. The water itself was not specifically modeled but the water in the pipes were included in the model as a non-participating structural mass. Which is to say the water mass is evenly distributed about the structure but does not alter the material or dimensional properties of the pipes. The pipes were modeled with ASTM A106 Grade B Carbon Steel material properties.

The target pipe was modeled as a span of pipe supported at each end. At both ends the pipe was constrained axially (X direction) via a rigid spring. The pipe was rigidly supported from translational motion in the directions perpendicular to the pipe axis (Y-Z). Rotationally, the target pipe was allowed some movement about all axes via rotational springs. The length of the target pipe is based upon recommended B31.1 maximum support spacing as detailed in Assumption #7..

The catastrophic failure of the moving pipe produces a jet force at the failed end which produces a moment arm and causes the pipe to rotate about a plastic hinge. This moment arm is conservatively assumed to be 15 ft in length and based upon previous testing (Ref. 2) is assumed to contact the target pipe 10 ft from the plastic hinge. The pipe rotates in a plane perpendicular to the axis of the target pipe and impacts the target pipe in a perfect "cross" blow at some point in its travel. The jet or blowdown force acting on the broken end of the moving pipe is determined via the equation $F_{bd} = 1.2 \times P_{op} \times A_{cs}$ where $P_{op}$ is the line operating pressure and $A_{cs}$ = Pipe Cross Sectional Area. (Ref 10)

The actual Blowdown Force acting on Projectile Pipe for the bounding interaction cases are as follows:

Blowdown force $F_p := \overrightarrow{\left(1.2P_p \cdot A_{p.I}\right)}$ $F_p = \begin{pmatrix} 3.8\times10^4 \\ 5.7\times10^4 \\ 9.2\times10^4 \\ 1.5\times10^5 \\ 9.2\times10^4 \\ 1.5\times10^5 \end{pmatrix}\cdot \text{lbf}$

Two modeling scenarios were considered for the projectile pipe. In the first scenario at time = 0 the moving pipe was modelled just contacting the target pipe with a calculated angular velocity. The initial velocity was calculated assuming the projectile pipe rotates about a purely plastic hinge which offers no rotational resistance. The hinged end is constrained from any translational movement or rotation about any other axis. This scenario was much to conservative and too limiting when considering larger diameter moving pipes. Reference 5 addresses this modelling scenario as completely theoretical and not being a credible "real-life" piping system behavior.

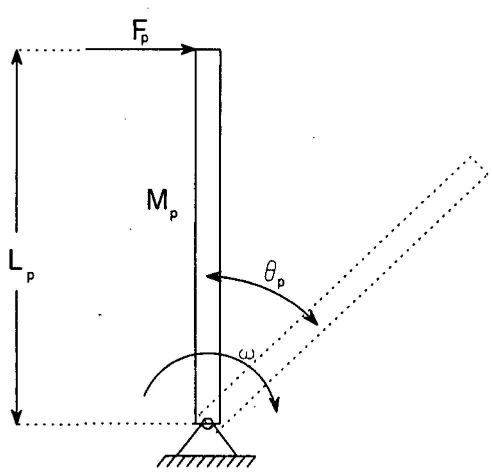
A more realistic modelling approach was possible due to the capabilities of the LS-DYNA software. This software allowed the entire actual event to be modelled rather just a portion which used theoretical, ideal initial conditions as inputs. Specifically the model was made using actual bounding orientations of Target pipe vs Projectile pipe interactions as obtained from Reference 7. At t =0 an instantaneous force was applied to the stationary projectile pipe simulating the blowdown force due to a pipe break. The other end of the projectile pipe was constrained as would be the case in an actual piping system. The model calculated the formation of the actual plastic hinge in the projectile or moving pipe rather than assuming an ideal actual hinge at an assumed location. As this hinge formed the projectile pipe rotates via the blowdown force and contacts the Target pipe. The software then determines the deformation and the residual damage to both pipes at the conclusion of the event.

Velocity at impact was determined using actual separation distances determined for specific interaction pairs considered from Reference 7. The interaction pairs could be categoried in two general groups, those where the moving pipe is thinner than the target pipe and those where the two pipe thickness are equal and the target pipe thickness to diameter ratio is less than 0.065. Additionally the interaction pairs contain only 3 distinct target pipe sizes, 24 inch, schedule 20; 16 inch, schedule 30 and 14 inch, schedule xs pipe.

### 6.2 Determination of Bounding Cases

Reference 7 identifies all of the applicable pipe interactions for the Turbine Building area where the projectile pipe thickness is either equal to or less than the target pipe thickness. From these interaction cases several critical cases were selected for detailed analysis. The interaction cases are summarize in tables in this section for all the interaction pairs for the respective target pipe sizes. The bounding interactions are highlighted in yellow. The bounding interactions were mostly identified using engineering judgement / logic by comparing critical parameters such as separation distance, operating pressure, size of target vs moving pipe and relative thickness of each pipe.

In cases where these parameters did not clearly differentiate the interaction a calculation of the theoretical impact momentum was performed to allow relative comparison of impact severity between specific pipe interactions. The higher the momentum of the projectile pipe, the higher the potential for damage to the target pipe. The method for calculating the theoretical impact momentum of the projectile pipe is shown below (the calculation is theoretical because the moving pipe is assumed to rotate about a pinned connection located at the end of the pipe with no resistance to rotation):




Moment at plastic hinge assuming moving pipe has pinned connection (no resistance to rotation) $M_p := (F_p \cdot L_p)$

Moment of Inertia of the rotating pipe $I_p := \frac{m_p \cdot L_p \cdot L_p^2}{3}$

From conservation of Energy $M_t \cdot \theta = \frac{1}{2} \cdot I_t \cdot \omega^2$

Solving for angular velocity at impact $\omega = \sqrt{\frac{2 \cdot M_p \cdot \theta}{I_p}}$

Where angle of rotation at impact is (see Figure XX for X and Y) $\theta = \mathrm{asin}\left(\frac{X}{\sqrt{X^2 + Y^2}}\right)$

Velocity at Impact $v_p = 0.667 \cdot L_p \cdot \omega$

Momentum per unit weight at impact $P_I = m_p \cdot v_p$

**14 inch Target Pipe**

| Interaction | Pipe ID | Sched | ID | Wall Thickness | Target ID | Sched | Wall Thickness | High Energy pipe operating pressure | Separation Distance (Inches) | Impact Velocity, ft/sec | Impact Momentum per unit wt, lbf*sec/ft |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 190 | 8-2HD-8 [41] | 80 | 7.625 | 0.5 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 48 | 161 | 321 |
| 188 | 8-2HD-6 [41] | 80 | 7.625 | 0.5 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 48 | 161 | 321 |
| 191 | 12-2CD-10 [40] | std | 12 | 0.375 | 14-ZX-161 [53] | XS [57] | 0.5 | 420 | 48 | 163 | 501 |
| 187 | 14-2HD-36 [41] | std | 13.25 | 0.375 | 14-ZX-161 [53] | XS [57] | 0.5 | 360 | 24 | 120 | 425 |
| 181 | 2 1/2-2HD-82 [46] | 80 | 2.323 | 0.276 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 3 | | |
| 192 | 2 1/2-2HD-83 [46] | 80 | 2.323 | 0.276 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 24 | | |
| 182 | 6-2HD-6 [41] | 80 | 5.761 | 0.432 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 36 | | |
| 183 | 6-2HD-8 [41] | 80 | 5.761 | 0.432 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 2 | | |
| 135 | 8-2HD-28 [41] | 40 | 7.981 | 0.322 | 14-ZX-161 [53] | XS [57] | 0.5 | 165 | 2 | | |
| 134 | 8-2HD-29 [41] | 40 | 7.981 | 0.322 | 14-ZX-161 [53] | XS [57] | 0.5 | 165 | 84 | 124 | 192 |
| 136 | 8-2HD-29 [41] | 40 | 7.981 | 0.322 | 14-ZX-161 [53] | XS [57] | 0.5 | 165 | 36 | | |
| 142 | 8-2HD-29 [41] | 40 | 7.981 | 0.322 | 14-ZX-161 [53] | XS [57] | 0.5 | 165 | 48 | | |
| 184 | 8-2HD-6 [41] | 80 | 7.625 | 0.5 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 12 | | |
| 185 | 8-2HD-8 [41] | 80 | 7.625 | 0.5 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 1 | | |
| 189 | 8-2HD-8 [41] | 80 | 7.625 | 0.5 | 14-ZX-161 [53] | XS [57] | 0.5 | 685 | 36 | | |

### 16 inch Target Pipe

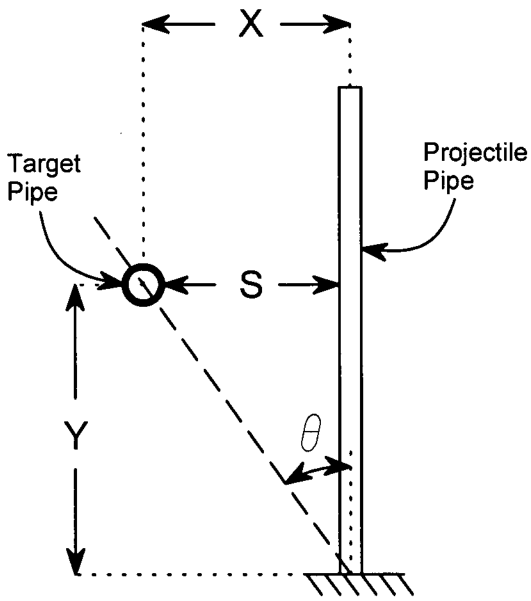
| Interaction | Pipe ID | Sched | ID | Wall Thickness | Target ID | Sched | Wall Thickness | High Energy pipe operating pressure | Separation Distance (Inches) | Impact Velocity, ft/sec | Impact Momentum, lbf*sec/ft |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 20-CD-7 [44] | 20 | 19.25 | 0.375 | 16-CL-67 [30] | 30 | 0.375 | 420 | 16 | 133 | 846 |
| 19 | 16-CD-9 [44] | 30 | 15.25 | 0.375 | 16-CL-67 [30] | 30 | 0.375 | 420 | 36 | 158 | 697 |
| 109 | 16-2CD-9 [40] | 30 | 15.25 | 0.375 | 16-2CL-9 [32] | 30 | 0.375 | 420 | 36 | 158 | 697 |
| 114 | 12-2CD-7 [40] | 40S | 12 | 0.375 | 16-2CL-9 [32] | 30 | 0.375 | 420 | 16 | | |
| 115 | 20-2CD-7 [40] | 20 | 19.25 | 0.375 | 16-2CL-9 [32] | 30 | 0.375 | 420 | 6 | | |
| 121 | 16-2CD-7 [40] | 30 | 15.25 | 0.375 | 16-2CL-9 [32] | 30 | 0.375 | 420 | 12 | | |
| 14 | 12-CD-7 [44] | 40S | 12 | 0.375 | 16-CL-67 [30] | 30 | 0.375 | 420 | 36 | | |
| 18 | 16-CD-7 [44] | 30 | 15.25 | 0.375 | 16-CL-67 [30] | 30 | 0.375 | 420 | 16 | | |

### 24 inch Target Pipe

| Interaction | Pipe ID | Sched | ID | Wall Thickness | Target ID | Sched | Wall Thickness | High Energy pipe operating pressure | Separation Distance (Inches) | Impact Velocity, ft/sec | Impact Momentum, lbf*sec /ft |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 123 | 20-2CD-7 [40] | 20 | 19.25 | 0.375 | 24-2CL-56 [32] | 20 | 0.375 | 420 | 24 | 155 | 990 |
| 20 | 20-CD-7 [44] | 20 | 19.25 | 0.375 | 24-CL-110 [30] | 20 | 0.375 | 420 | 24 | 155 | 990 |
| 20a | 20-CD-7 [44] | 20 | 19.25 | 0.375 | 24-CL-110 [30] | 20 | 0.375 | 420 | 24 | 155 | 990 |
| 48 | 16-CD-10 [44] | 30 | 15.25 | 0.375 | 24-CL-110 [30] | 20 | 0.375 | 420 | 60 | 201 | 889 |
| 168 | 16-2CD-10 [40] | 30 | 15.25 | 0.375 | 24-2CL-56 [32] | 20 | 0.375 | 420 | 36 | | |
| 169 | 16-2CD-7 [40] | 30 | 15.25 | 0.375 | 24-2CL-56 [32] | 20 | 0.375 | 420 | 24 | | |
| 161 | 8-2HD-28 [41] | 40 | 7.981 | 0.322 | 24-2CL-56 [32] | 20 | 0.375 | 165 | 1 | | |
| 164 | 8-2HD-28 [41] | 40 | 7.981 | 0.322 | 24-2CL-56 [32] | 20 | 0.375 | 165 | 96 | 143 | 222 |
| 60 | 16-CD-7 [44] | 30 | 15.25 | 0.375 | 24-CL-110 [30] | 20 | 0.375 | 420 | 36 | | |
| 49 | 8-HD-28 [45] | 40 | 7.981 | 0.322 | 24-CL-110 [30] | 20 | 0.375 | 165 | 16 | | |
| 56 | 8-HD-28 [45] | 40 | 7.981 | 0.322 | 24-CL-110 [30] | 20 | 0.375 | 165 | 6 | | |

**6.3 Determination of Initial Pipe Positions for Specific Controlling Interactions**

The pipe separation distance (S) was provided in Reference (7). Assumption #2 specifies that the projectile pipe is 15 ft long. Assumption #3 states that the location of theoretical contact was taken at a distance of about 2/3 this length, or 10 ft. Based on these parameters, the elevation of the target pipe or distance Y was determined. Smaller distances of Y were considered which would increase the angle of rotation at contact, but reduce the moment arm between the hinge and the target pipe. By comparing the impact velocity, it was determined that the worst case was when Y was maximized. This will be further demonstrated at the end of this section when the impact velocities are recalculated using Y = 0 (and thus θ = 90 degrees).




$$S := \begin{pmatrix} 4.0 \\ 4.0 \\ 3.0 \\ 1.333 \\ 5.0 \\ 2.0 \end{pmatrix} ft$$

$$X := S + 0.5 \cdot (D_{p.o} + D_{t.o})$$

$$X = \begin{pmatrix} 4.9 \\ 5.1 \\ 4.3 \\ 2.8 \\ 6.7 \\ 3.8 \end{pmatrix} ft$$

Vertical position of Target Pipe to allow a theoretical impact location of 10 ft on the Projectile Pipe

$$Y := \overrightarrow{\left[\sqrt{(10 \cdot ft)^2 - X^2}\right]}$$

$$Y = \begin{pmatrix} 8.7 \\ 8.6 \\ 9.0 \\ 9.6 \\ 7.5 \\ 9.2 \end{pmatrix} ft$$

Angle of rotation at impact

$$\theta := \overrightarrow{\operatorname{asin}\left(\frac{X}{\sqrt{X^2 + Y^2}}\right)} \qquad \theta = \begin{pmatrix} 29.6 \\ 30.8 \\ 25.7 \\ 16.5 \\ 41.8 \\ 22.5 \end{pmatrix} \cdot \mathrm{deg}$$

Angular Velocity at Impact

$$\omega := \overrightarrow{\sqrt{\frac{2 \cdot M_p \cdot \theta}{I_p}}} \qquad \omega = \begin{pmatrix} 16.2 \\ 16.3 \\ 15.8 \\ 13.3 \\ 20.2 \\ 15.6 \end{pmatrix} \cdot \frac{\mathrm{rad}}{\mathrm{sec}}$$

Impact Velocity

$$v_p := \overrightarrow{(10 \cdot \mathrm{ft} \cdot \omega)} \qquad v_p = \begin{pmatrix} 162 \\ 163 \\ 158 \\ 133 \\ 202 \\ 156 \end{pmatrix} \frac{\mathrm{ft}}{\mathrm{s}}$$

Momentum at Impact per unit pipe weight

$$M_I := \overrightarrow{(m_p \cdot v_p)} \qquad M_I = \begin{pmatrix} 319 \\ 500 \\ 696 \\ 845 \\ 888 \\ 988 \end{pmatrix} \frac{1}{\mathrm{ft}^2} \cdot \mathrm{ft} \cdot \mathrm{lbf} \cdot \mathrm{s}$$

Check case for Y=0, and θ = 90 degrees

Angle of rotation at impact $\theta 2 := 90 \cdot deg$ $\theta 2 = 90 \cdot deg$

Angular Velocity at Impact $\omega 2 := \overrightarrow{\sqrt{\frac{2 \cdot M_p \cdot \theta 2}{I_p}}}$ $\omega 2 = \begin{pmatrix} 28.3 \\ 27.9 \\ 29.6 \\ 31.1 \\ 29.6 \\ 31.1 \end{pmatrix} \cdot \frac{rad}{sec}$ $\omega = \begin{pmatrix} 16.2 \\ 16.3 \\ 15.8 \\ 13.3 \\ 20.2 \\ 15.6 \end{pmatrix} \cdot \frac{rad}{sec}$

Impact Velocity $v_{p2} := \overrightarrow{(X \cdot \omega 2)}$ $v_{p2} = \begin{pmatrix} 140 \\ 143 \\ 128 \\ 88 \\ 197 \\ 119 \end{pmatrix} \frac{ft}{s}$ $v_p = \begin{pmatrix} 162 \\ 163 \\ 158 \\ 133 \\ 202 \\ 156 \end{pmatrix} \frac{ft}{s}$

As demonstrated, although the angular velocity is greater when the Y distance is taken as zero (i.e., hinge forms right at the same height as the target pipe), due to the smaller moment arm, the impact velocity is less for this case. Therefore maximizing the Y distance produces a higher impact velocity, and therefore a higher potential for damage to the target pipe. Also note that this analysis does not consider the effect of reduced blowdown flow due to the reduced cross-sectional area at the hinge or buckling location in the projectile pipe, and the corresponding force reduction associated with large values of θ (see Section 6.5 for additional discussion).

### 6.4 Boundary Conditions

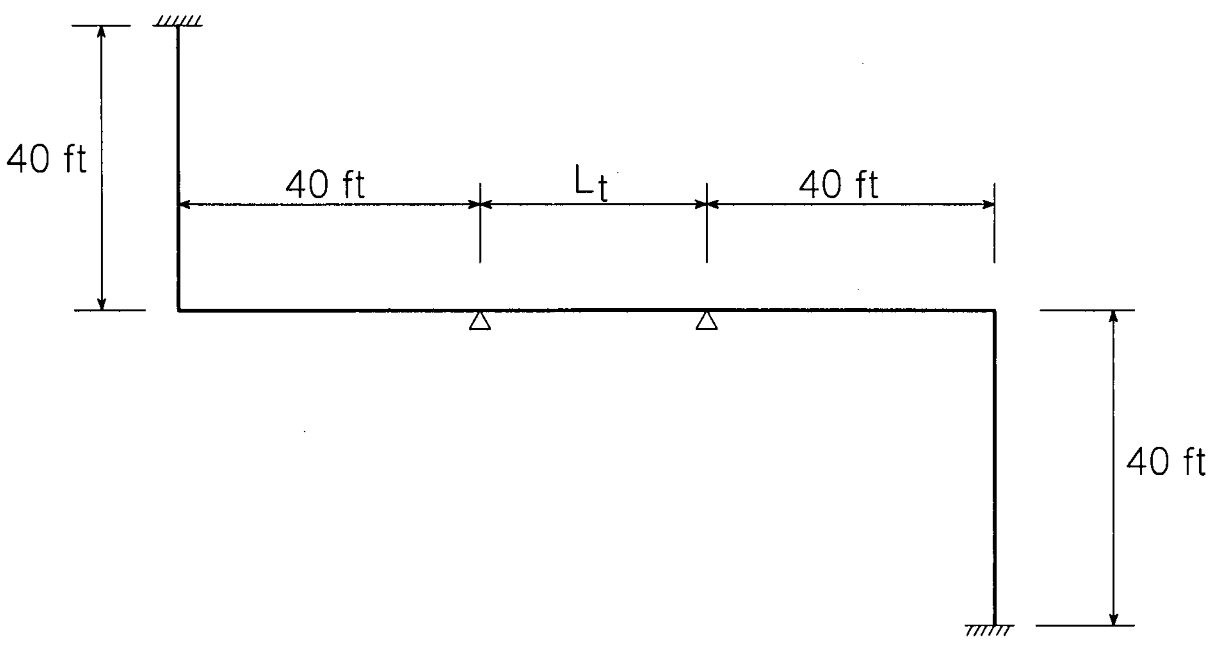
The boundary conditions for both the target pipe and the projectile pipe need to be established to provide a realistic approximation of the actual configuration. Certain assumptions have been made for the length of the target pipe, and the relative location of the contact point along the length of the projectile pipe as discussed in Section 6.3. The boundary conditions for both the projectile pipe and the target pipe will be discussed in this section.

The boundary conditions for the projectile pipe are fairly simple. At the break location, the projectile pipe is conservatively considered free to displace based on the assumption of a full cross section guillotine break. A force is applied at the end of the projectile pipe perpendicular to the pipe axis. In order to preserve the integrity of the model behavior, a reinforcing ring is added to the model on the end of the projectile pipe where the load is applied to facilitate even load distribution to the model elements around the end of the pipe ensuring there is no localized deformation there. As it pertains to the real life situation, it is assumed there is a 90 degree elbow at the top of the break which is causing the whipping force. Note that the elbow was not modelled in LS-DYNA to simplify the modeling effort. The use of the rigid ring on the free end of the pipe is conservative in comparison to actually modelling the elbow in LS-DYNA.

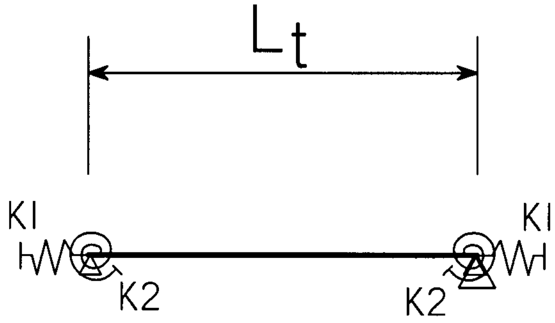
At the opposite end the projectile is fixed as an anchor. This end condition is conservative from the perspective that it will not allow deflection or displacement of the projectile pipe at this location up to and through pipe impact thus maximizing imparted energy to the target pipe. As can be seen from the results in Section 6.6, a plastic hing forms in the moving pipe at some distance above the fixed end of the moving pipe (approximately 1 to 2 diameters above the fixed point location. The consequential damage that occurs in the projectile pipe below the hinge point is not relevant to this investigation.

The boundary conditions placed upon the target pipe are more sophisticated and indicative of the remainder of the piping system which brackets the target pipe on each end. A single span of the target pipe was considered. In order to account for the continuation of the pipe, spring restraints were used on both ends of the target pipe. Parametric runs were made (see Section 6.7) that confirmed that the smaller the stiffness values of these springs, the higher the potential for damage to the target pipe. Conservatively low spring stiffnesses were used based on relatively long unsupported spans of the target pipe. Since the target pipes are non-safety, non-seismic, it is conservatively assumed that the pipe is mostly supported by spring or rod hangers with very few lateral supports. A conservative support scheme was used to calculate representative stiffnesses as shown on the next page.

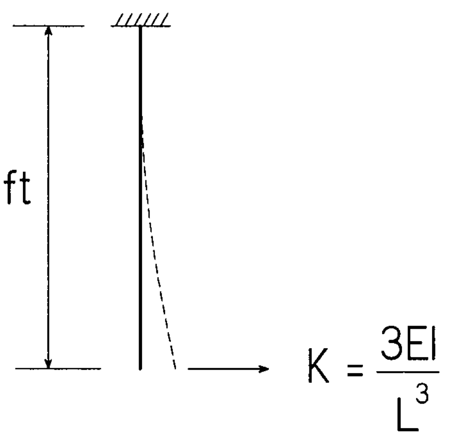
Evaluation has shown that damage results are sensitive to the span of the target pipe between supports. The degree of sensitivity depends upon a number of key factors including relative pipe thickness to each other, magnitude of the blowdown force, initial separation distance, etc. Parametric runs performed in Section 6.7 indicate that for the case where only the angular velocity is considered, a shorter pipe span produces the most conservative results. However, for cases where the jet force continues to be applied after the initial contact with the pipe, the longer the span the worse the damage to the target pipe. For this evaluation a reasonable support span of 1/2 the maximum recommended per ASME B31.1 was utilized.




40 ft spans are considered in two directions on either side of the supports in the target pipe impact zone. At the ends the pipe is considered fixed assuming it terminates into some piece of equipment or anchor at a wall penetration. These spans are considered conservatively large. Using these spanse stiffness values are considered for the target pipe so it can be modelled as shown below:




The axial stiffness is based on a simple cantilever bending of a 40 ft cantileved pipe as shown in the figure below




$L := 40 \cdot ft$ $E := 27.9 \cdot 10^6 \cdot psi$ (Ref 9)

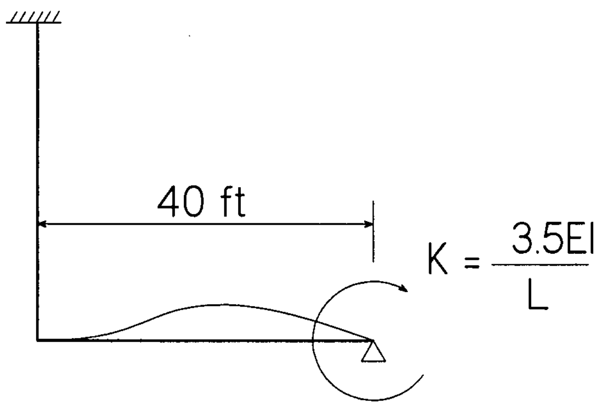
$$I := \begin{pmatrix} 483.8 \\ 562.1 \\ 1942 \end{pmatrix} \cdot in^4$$ 14" XS, 16" Sch. 30, 20" Sch. 20

$$K1 := \frac{3 \cdot E \cdot I}{L^3} \qquad K1 = \begin{pmatrix} 366 \\ 425 \\ 1470 \end{pmatrix} \cdot \frac{lbf}{in}$$

Use 500 lb/in for 14" and 16" pipe

Use 1000 lb/in for 24" pipe

For the rotational springs, the spring stiffness for a unit rotation is 4EI/L for a fixed end, and 3EI/L for a pinned end (Ref. 4). Since the end of the pipe segment has some flexibility due to the next 40 ft leg, use a stiffness of 3.5EI/L to represent a mid point between fixed and pinned.




$$K2 := \frac{3.5 \cdot E \cdot I}{L} \qquad K2 = \begin{pmatrix} 9.8 \times 10^{7} \\ 1.1 \times 10^{8} \\ 4 \times 10^{8} \end{pmatrix} \cdot \frac{in \cdot lbf}{rad}$$

Use 1 x $10^8$ in-lbf/rad for 14" and 16" pipe

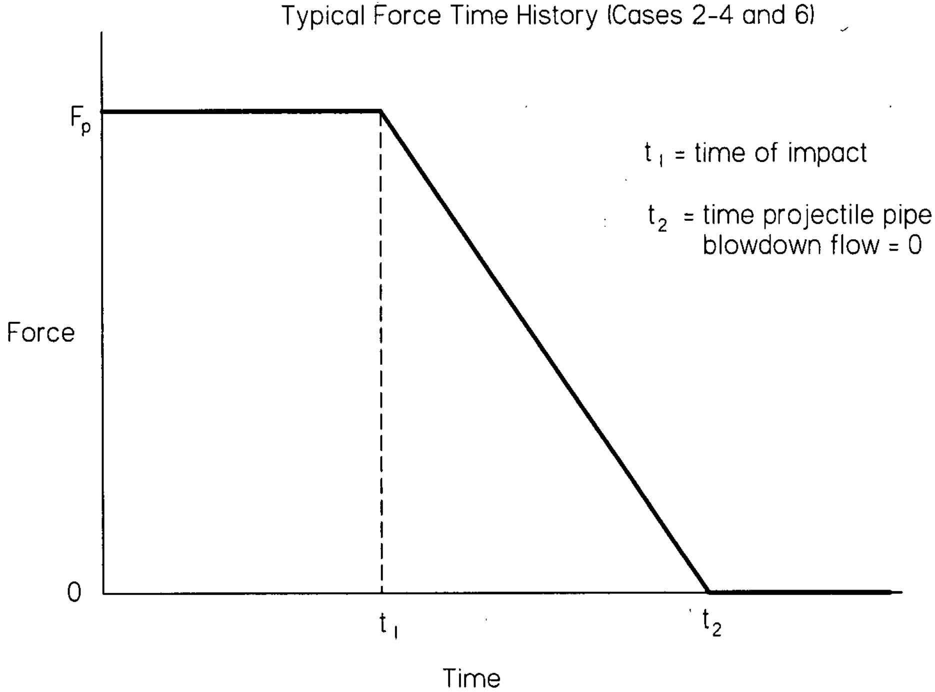
Use 2 x $10^8$ in-lbf/rad for 24" pipe

### 6.5 Jet Force Time History

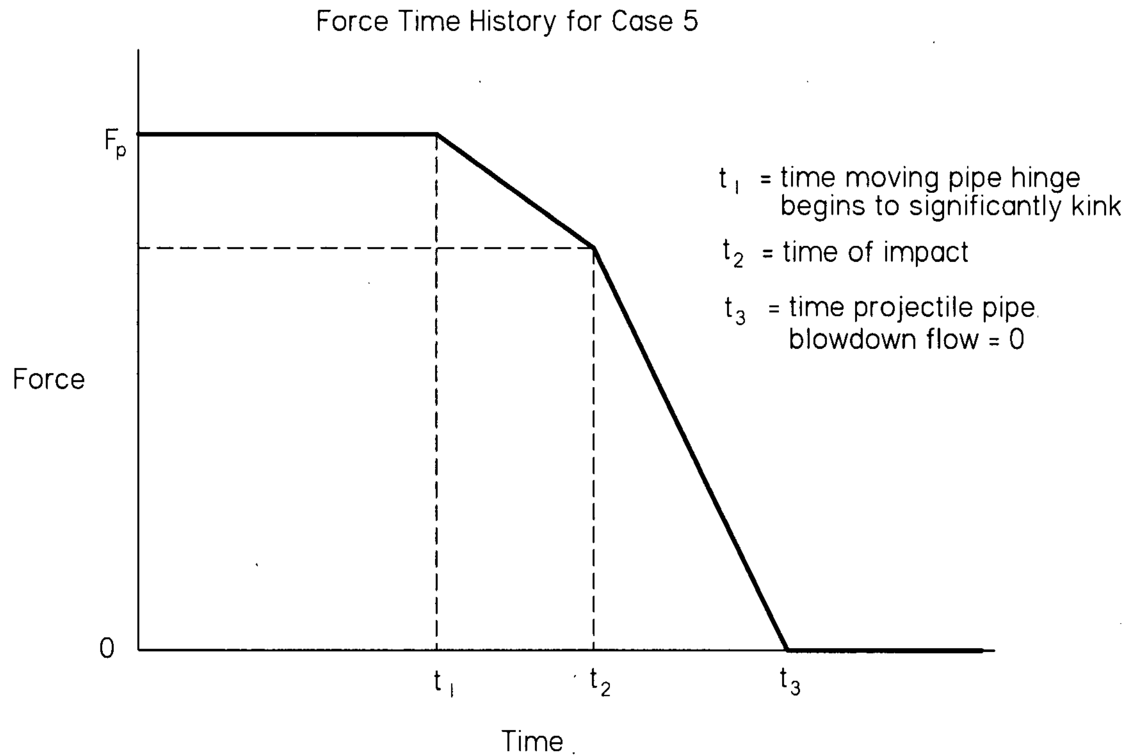
As the projectile pipe rotates about a plastic hinge, the cross-sectional area of the pipe is reduced. This occurs at two locations; at the hinge where the pipe buckles and at the impact location as the projectile pipe tends to wrap around the target pipe. As the pipe cross-sectional area is reduced there is a corresponding reduction in the blowdown flow from the pipe. This reduces the whipping force on the pipe as the pipe continues to deform. Following impact, as the collision continues, and both pipes deform, the flow is eventually reduced to zero at the point where the projectile pipe basically seals itself off and the blowdown force is gone.

To account for this force reduction, the LS-DYNA runs were used to estimate the reduced cross sectional areas at both the plastic hinge, and at the impact location. Data was taken from preliminary runs to determine the reduced area at the deformed cross sections at specific times during the event. Using this data, more realistic force functions were utilized in the Case runs by applying a force time history based on a linear reduction in the area. Conservatively, for most cases only the reduction of area at the collision point was considered. In one case, the reduction in the area at the moving pipe hinge location was also considered (for Case 5 where the separation distance was larger resulting in a large rotation in the moving pipe prior to impact. The shape of the force time history curve is shown below:

Typical Force Time History (Cases 2-4 and 6)



For Case 5, since the angle of rotation of the moving pipe was large, a two step force time history was used to account for the flow reduction at the plastic hinge.



### 6.6 Analysis Results

Six specific interaction cases were run as described in the sections above. A table summarizing the input parameters for these six load cases is provided below:

| | | | | | | | | | Target Pipe Boundary Conditions | | Moving Pipe Boundary Conditions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case | Target Pipe, OD, in | Target Wall t, in | Projectile Pipe, OD, in | Projectile Pipe, t, in | Target Span, ft | Separation Distance, ft | CL to CL separation distance, ft | Target pipe CL elevation, ft | Axial Spring, lb*in | Rotational Spring (all axes) | Supported End | Free End | Linear force reduction time steps, msec |
| Case 1 | 14 | 0.5 | 8.625 | 0.5 | 12.5 | 4 | 4.9 | 8.7 | 500 | 1.0E8 | Fixed | F=37,500lbs | No |
| Case 2 | 14 | 0.5 | 12.75 | 0.375 | 12.5 | 4 | 5.1 | 8.6 | 500 | 1.0E8 | Fixed | F=57,000lbs | $t_1$=64, $t_2$=81 |
| Case 3 | 16 | 0.375 | 16 | 0.375 | 13.5 | 3 | 4.333 | 9 | 500 | 1.0E8 | Fixed | F=92,100lbs | $t_1$=52, $t_2$=72 |
| Case 4 | 16 | 0.375 | 20 | 0.375 | 13.5 | 1.333 | 2.8 | 9.6 | 500 | 1.0E8 | Fixed | F=147,000lbs | $t_1$=32, $t_2$=62 |
| Case 5 | 24 | 0.375 | 16 | 0.375 | 16 | 5 | 6.6 | 7.5 | 1000 | 2.0E8 | Fixed | F=92,100lbs | $t_1$=55, $t_2$=69, $t_3$=82[1] |
| Case 6 | 24 | 0.375 | 20 | 0.375 | 16 | 2 | 3.8 | 9.2 | 1000 | 2.0E8 | Fixed | F=147,000lbs | $t_1$=40, $t_2$=70 |

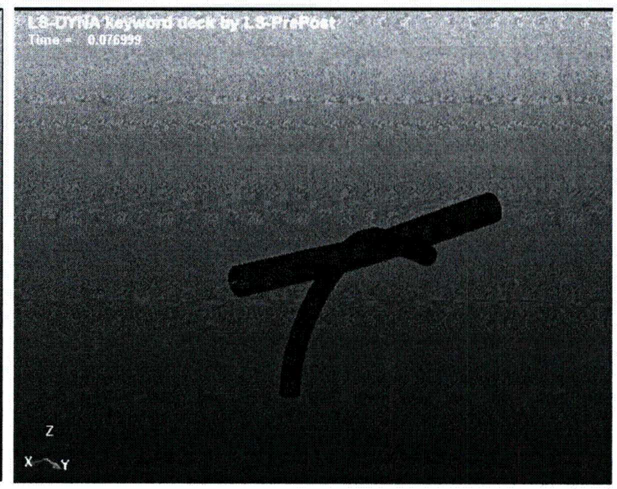
1 50% linear force reduction 55 to 69 msec based upon 50% reduction in Projectile Pipe Section in buckling zone at contact.

Results for these six analysis cases are provided in the sections below:

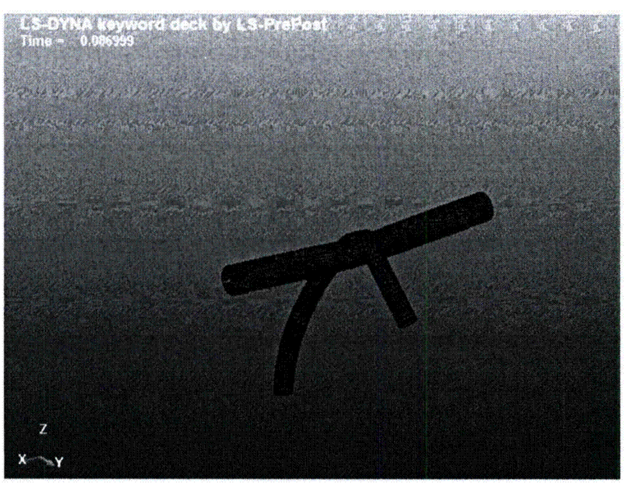
6.6.1 Case 1 (Interaction 188/190) - 14" XS Target Pipe, 8" XS Projectile Pipe

The figure below shows the deformation for both pipes at specific time points throughout the collision event

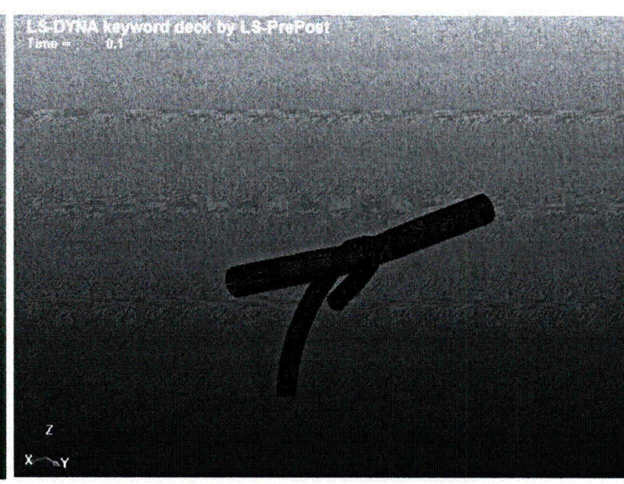

t = 0.065 msec (Initiation of contact)




t = 0.077 msec (Projectile Pipe Blowdown = 0)




t= 0.087 msec (Continued deformation)

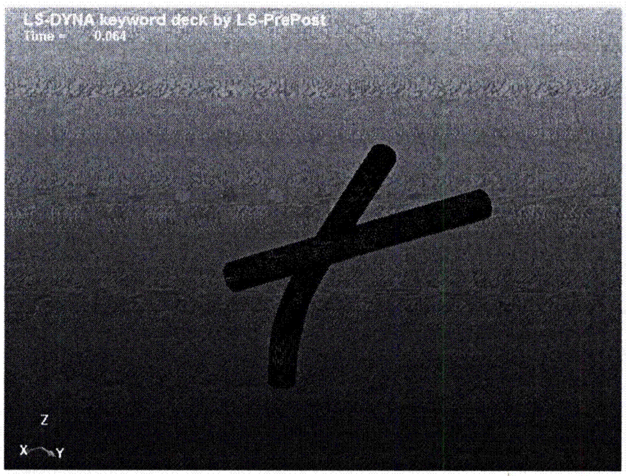



t = 0.100 msec (Conclusion of event)

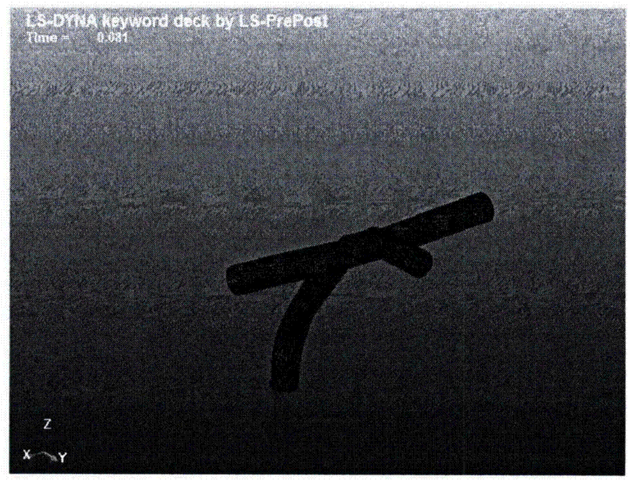
The results of the analysis show that no elements exceeded the strain limit of 25%. Therefore it is concluded that the interaction of the moving pipe with the target pipe will not create sufficient damage to the target pipe to add to the Turbine Building flooding concern.

6.6.2 <u>Case 2 (Interaction 190) - 14" XS Target Pipe, 12" Std Projectile Pipe</u>

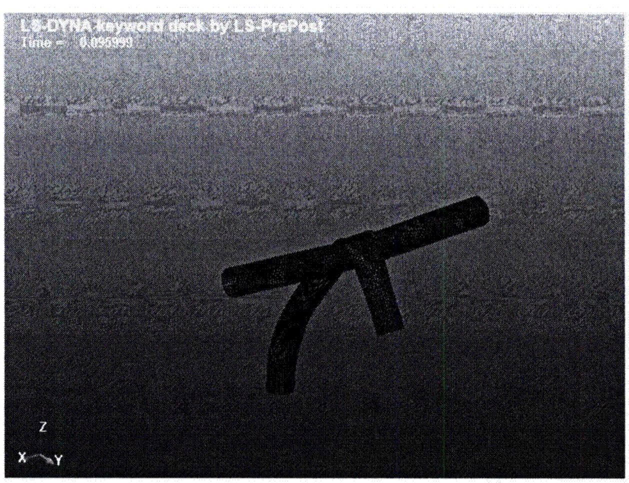
The figure below shows the deformation for both pipes at specific time points throughout the collision event



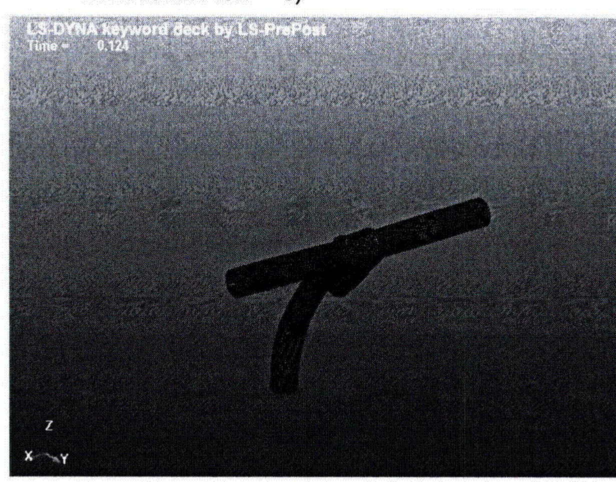

t = 0.064 msec (Initiation of contact)




t = 0.081 msec (Projectile Pipe Blowdown Flow = 0)




t= 0.096 msec (Continued deformation)

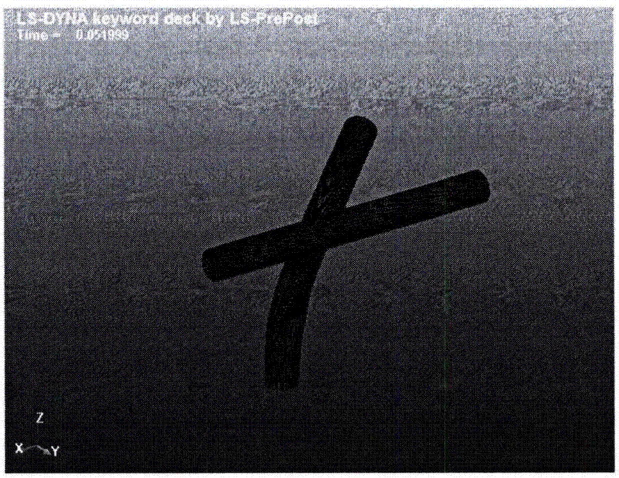



t = 0.124 msec (Conclusion of event)

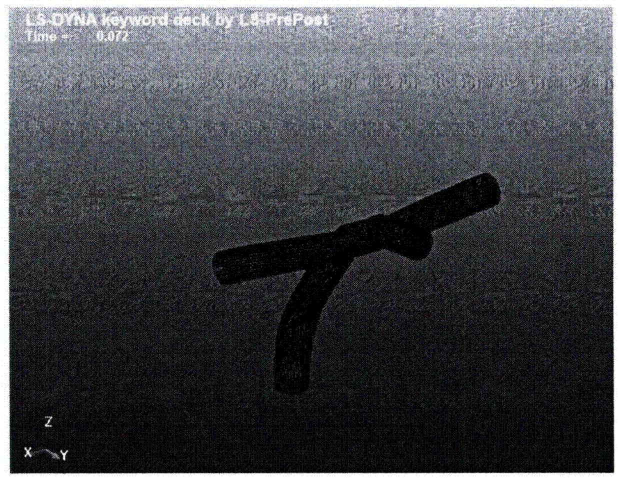
The results of the analysis show that no elements exceeded the strain limit of 25%. Therefore it is concluded that the interaction of the moving pipe with the target pipe will not create sufficient damage to the target pipe to add to the Turbine Building flooding concern.

6.6.3 Case 3 (Interaction 15) - 16" Sch. 30 Target Pipe, 16" Sch. 30 Projectile Pipe

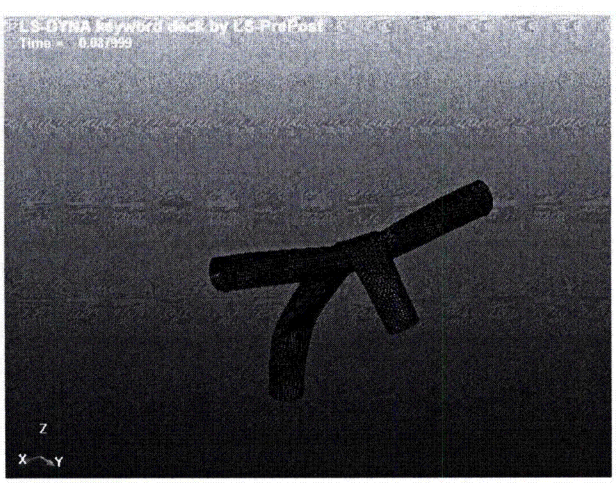
The figure below shows the deformation for both pipes at specific time points throughout the collision event



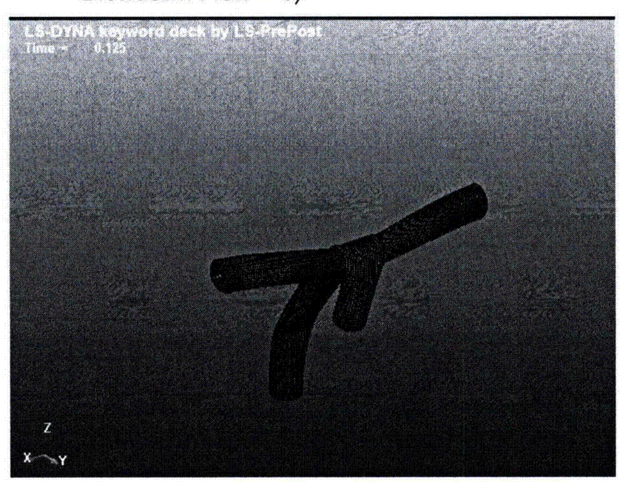

t = 0.052 msec (Initiation of contact)




t = 0.072 msec (Projectile Pipe Blowdown Flow = 0)




t= 0.088 msec (Continued deformation)

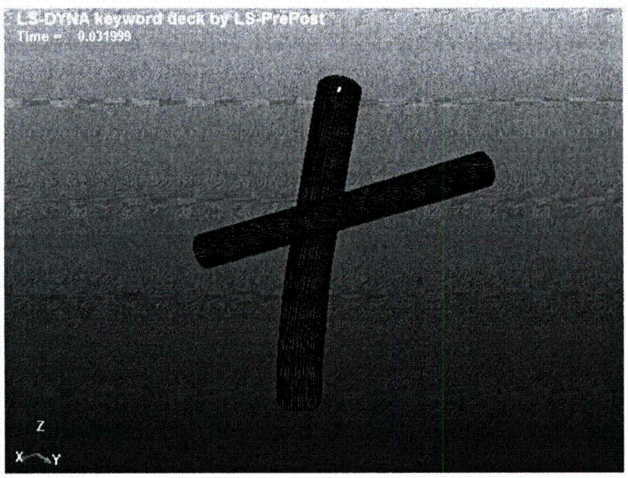



t = 0.125 msec (Conclusion of event)

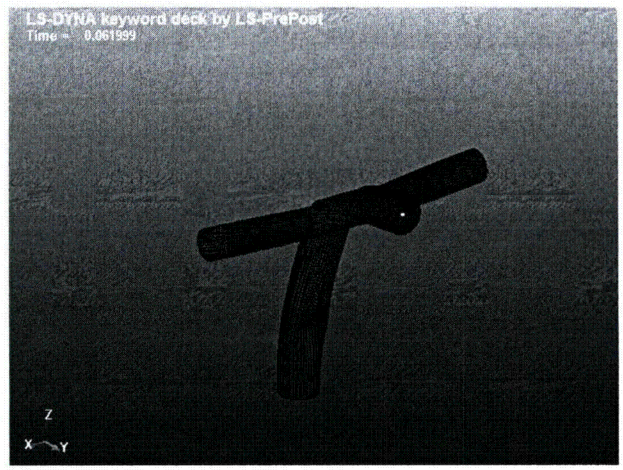
The results of the analysis show that 5 elements exceeded the strain limit of 25% creating a calculated surface area opening in the Target Pipe of 7.0 $in^2$. Because this pipe area opening is less than the acceptance criteria of 12.7 $in^2$ this piping interaction is not expected to cause adverse Turbine Building flooding.

6.6.4 Case 4 (Interaction 19/109) - 16" Sch. 30 Target Pipe, 20" Sch. 20 Projectile Pipe

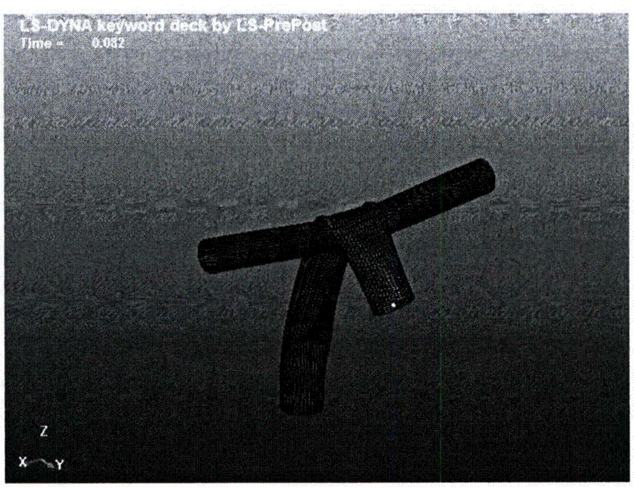
The figure below shows the deformation for both pipes at specific time points throughout the collision event



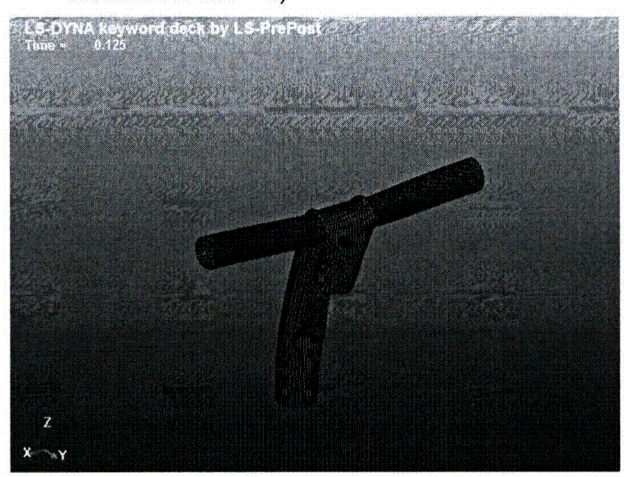

t = 0.032 msec (Initiation of contact)




t = 0.062 msec (Projectile Pipe Blowdown Flow = 0)




t= 0.082 msec (Continued deformation)

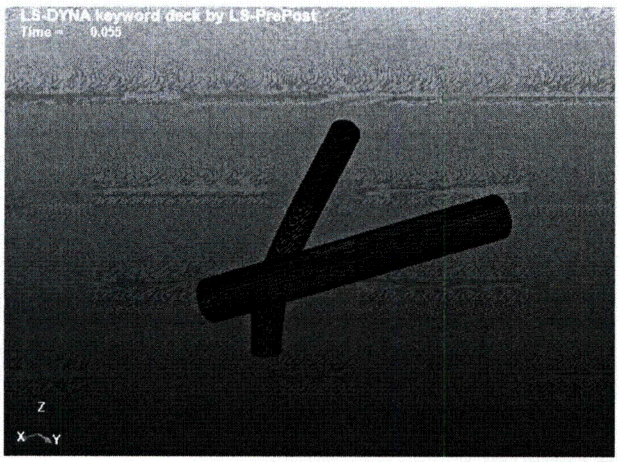



t = 0.125 msec (Conclusion of event)

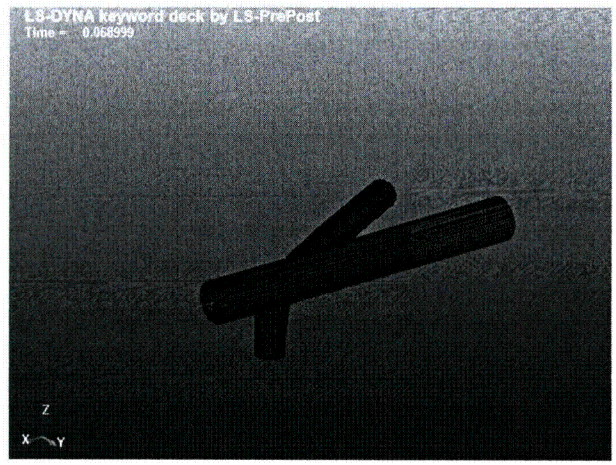
The results of the analysis show that 3 elements exceeded the strain limit of 25% creating a calculated surface area opening in the Target Pipe of 4.2 $in^2$. Because this pipe area opening is less than the acceptance criteria of 12.7 $in^2$ this piping interaction is not expected to cause adverse Turbine Building flooding.

6.6.5 Case 5 (Interaction 20/20a/123) - 24" Sch. 20 Target Pipe, 16" Sch. 30 Projectile Pipe

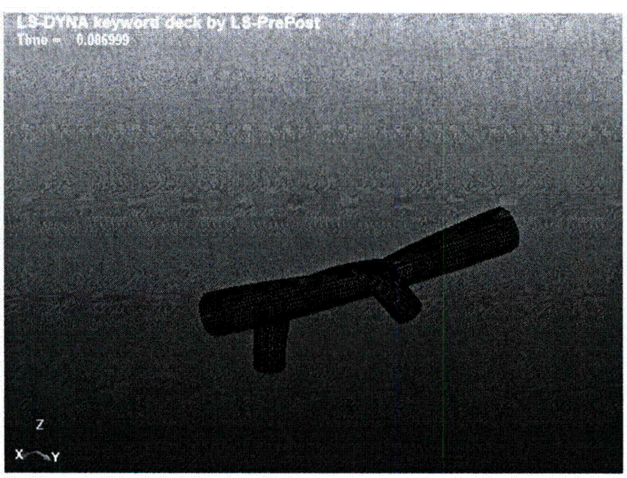
The figure below shows the deformation for both pipes at specific time points throughout the collision event



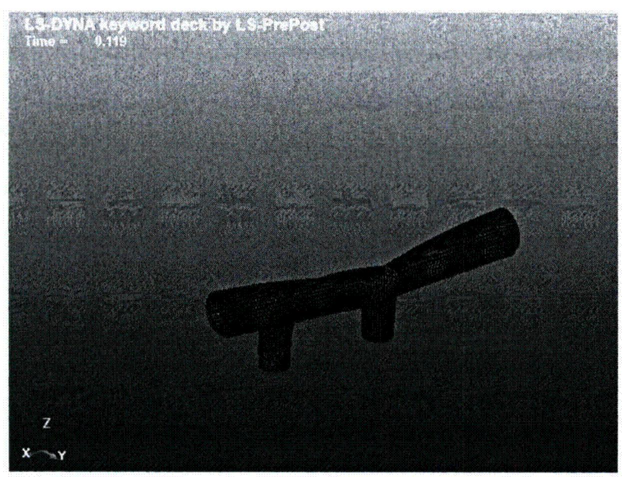

t = 0.055 msec (Cross-sectional area reduced 25% at hinge)




t = 0.069 msec (Initiation of contact)




t = 0.087 msec (Projectile Pipe Blowdown flow = 0)

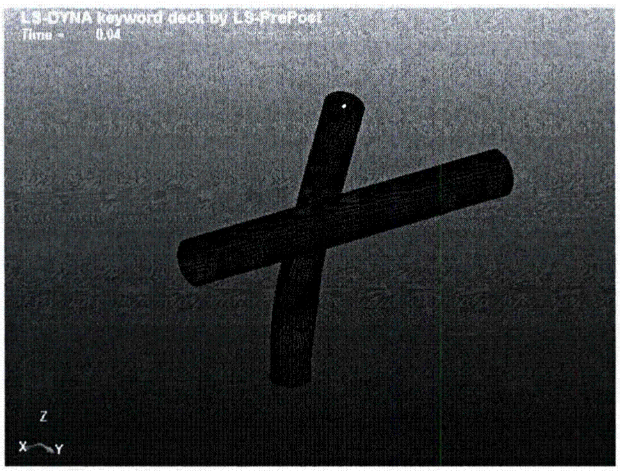



t = 0.119 msec (Conclusion of event)

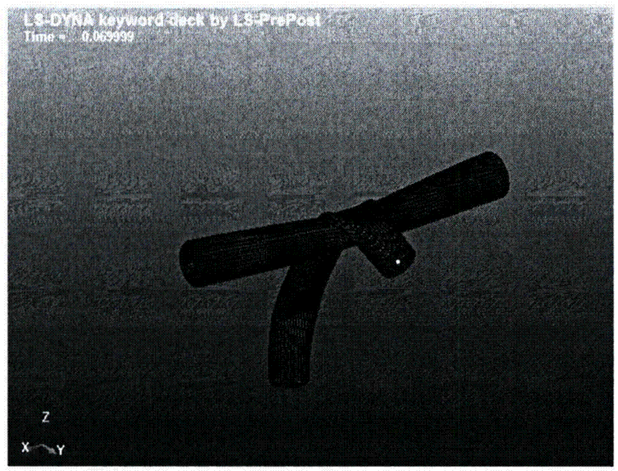
The results of the analysis show that 4 elements exceeded the strain limit of 25% creating a calculated surface area opening in the Target Pipe of 8.4 $in^2$. Because this pipe area opening is less than the acceptance criteria of 12.7 $in^2$ this piping interaction is not expected to cause adverse Turbine Building flooding.

6.6.6 Case 6 (Interaction 48) - 24" Sch. 20 Target Pipe, 20" Sch. 20 Projectile Pipe

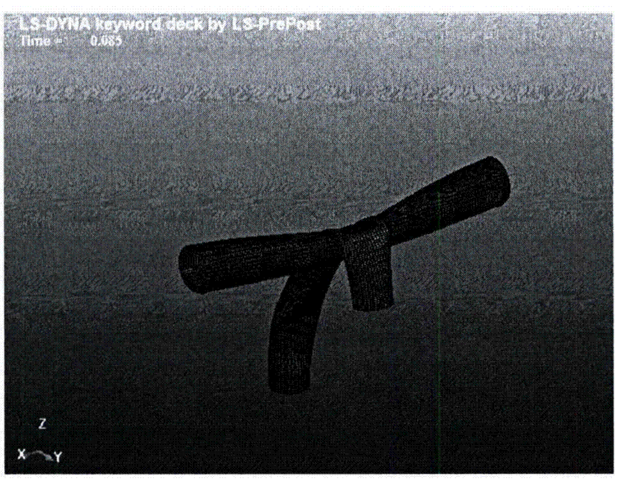
The figure below shows the deformation for both pipes at specific time points throughout the collision event



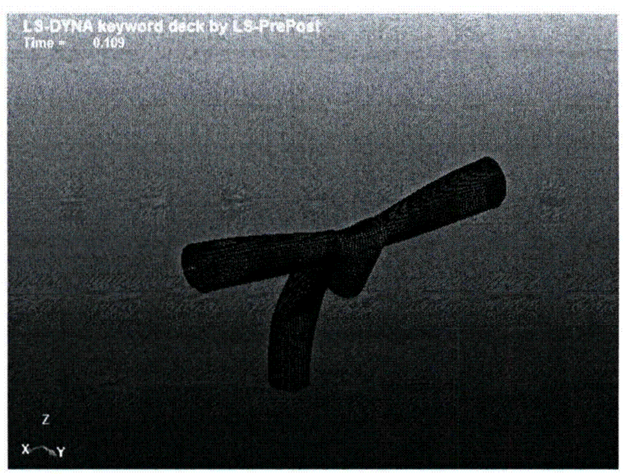

t = 0.040 msec (Initiation of contact)




t = 0.072 msec (Projectile Pipe Blowdown Flow = 0)




t= 0.085 msec (Continued deformation)




t = 0.109 msec (Conclusion of event)

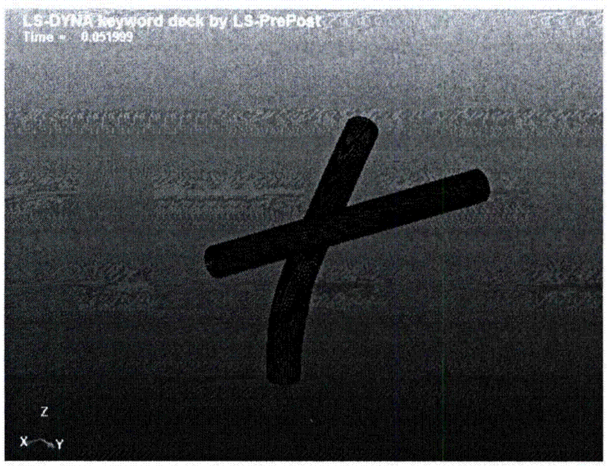
The results of the analysis show that 2 elements exceeded the strain limit of 25% creating a calculated surface area opening in the Target Pipe of 4.2 $in^2$. Because this pipe area opening is less than the acceptance criteria of 12.7 $in^2$ this piping interaction is not expected to cause adverse Turbine Building flooding.

**6.7 Parametric Evaluations**

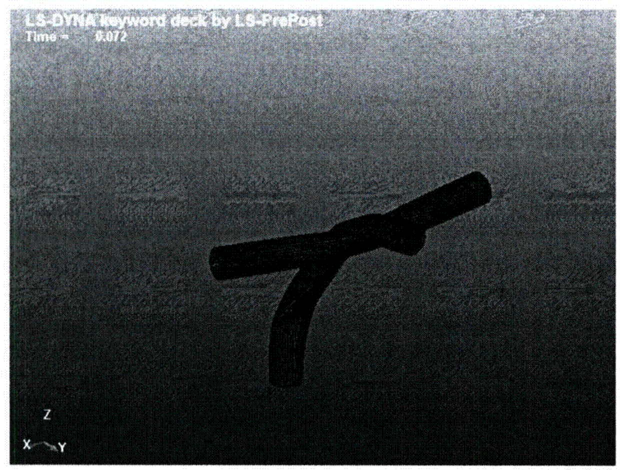
A few select additional cases were run to determine the impact of altering some of the key input parameters to determine the sensitivity of the results to the variation of these parameters. The results of these parametric runs are included on the following pages:

Case 7 - Reduce spring stiffness boundary conditions on the targey pipe by a factor of 5 (run on base Case 3 (Interaction 15) - 16" Sch. 30 Target Pipe, 16" Sch. 30 Projectile Pipe )

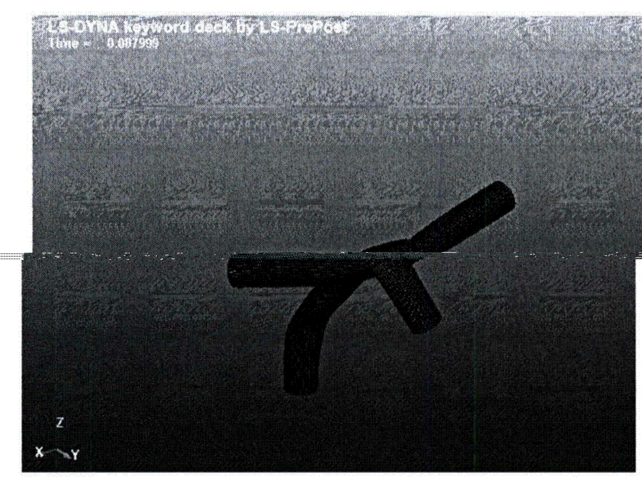
The results of this run confirmed that reducing the stiffness of the springs resulted in additional damage to the target pipe. Comparison of the screen shots below to those of the Base Case it is apparent that the lighter spring forces result in much more target pipe deformation. Since the stiffness used already represent lower bound values, the results from Cases 1 - 6 are still bounding. There is no need to make additional runs with stiffer springs as this will result in less damage to the target pipe.



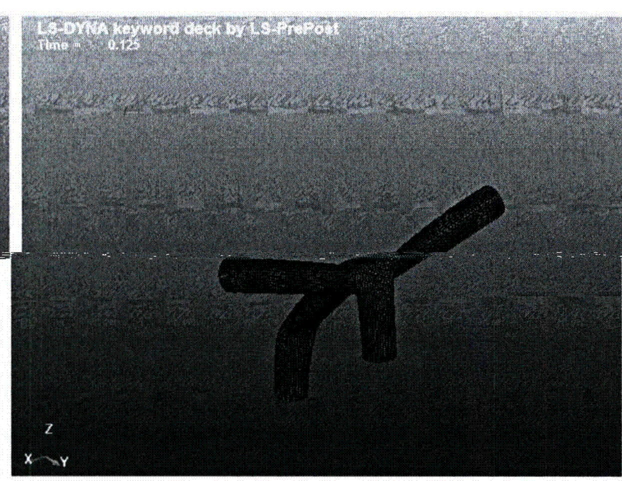

t = 0.052 msec (Initiation of contact)




t = 0.072 msec (Projectile Pipe Blowdown Flow = 0)

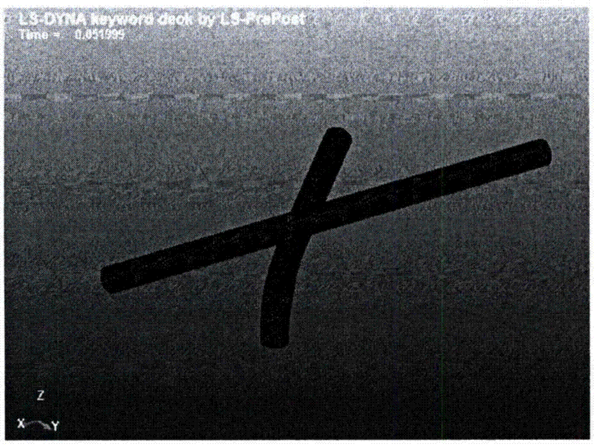



t= 0.088 msec (Continued deformation)

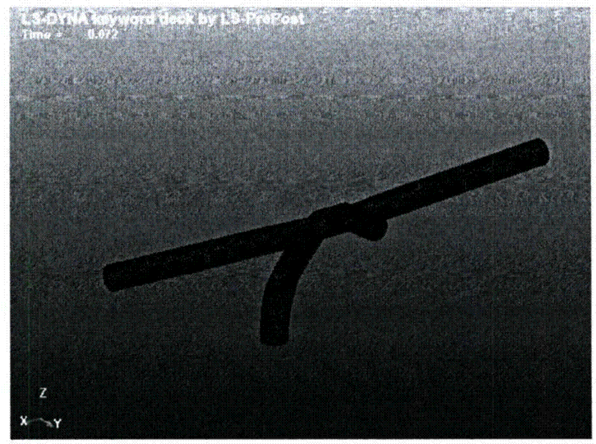



t = 0.125 msec (Conclusion of event)

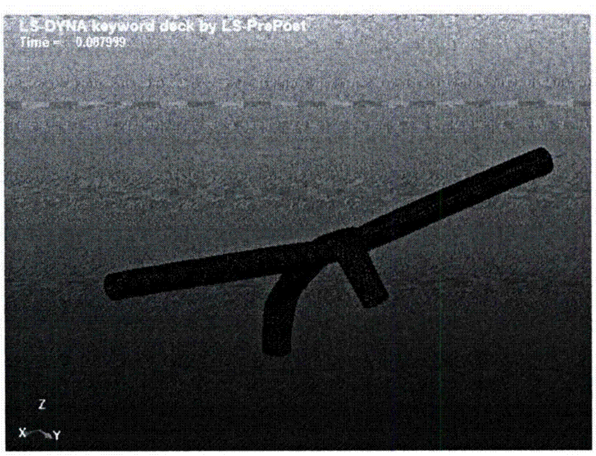
Case 8 - Increase support span on target pipe by a factor of 2 (run on base Case 3 (Interaction 15) - 16" Sch. 30 Target Pipe, 16" Sch. 30 Projectile Pipe )



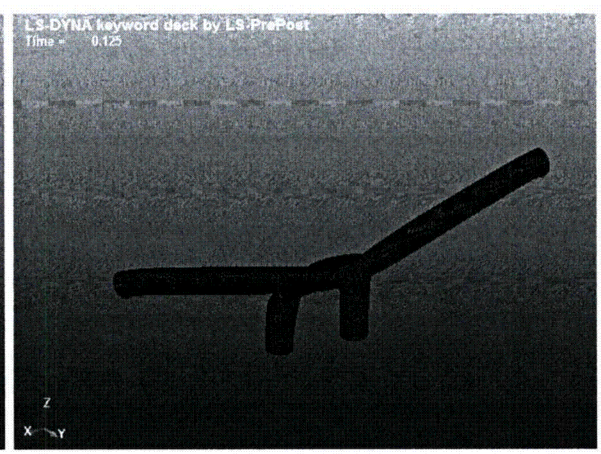

t = 0.052 msec (Initiation of contact)




t = 0.072 msec (Projectile Pipe Blowdown Flow = 0)

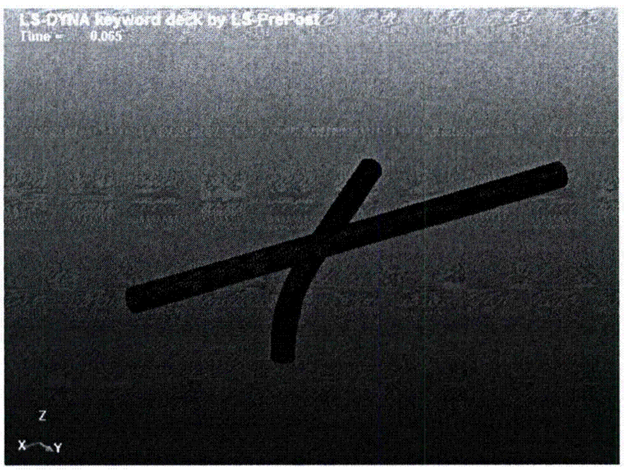



t= 0.088 msec (Continued deformation)

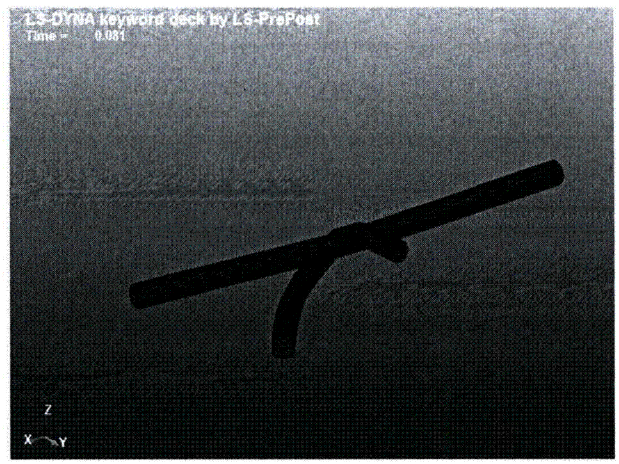



t = 0.125 msec (Conclusion of event)

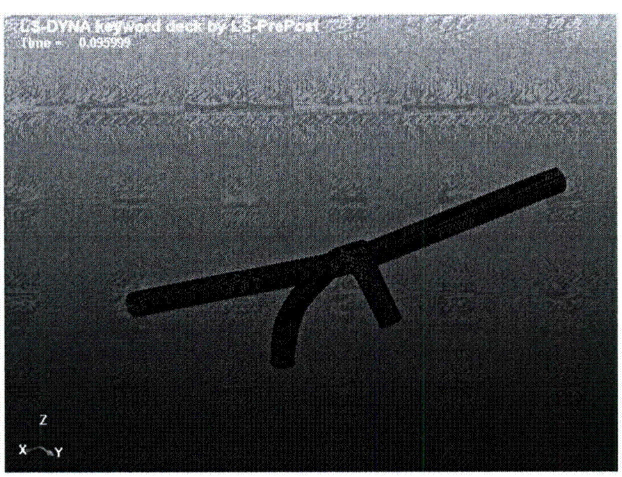
Case 9 - Increase support span of target pipe by a factor of 2 (run on base Case 2 <u>(Interaction 190) - 14" XS Target Pipe, 12" Std Projectile Pipe)</u>



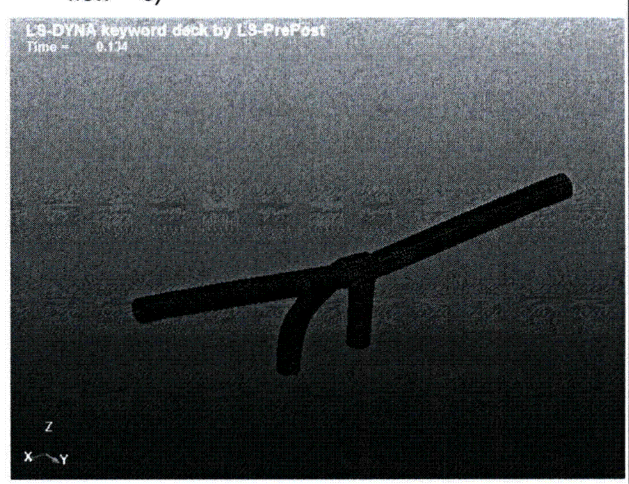

t = 0.065 msec (Initiation of contact)




t = 0.081 msec (Projectile pipe Blowdown flow = 0)




t= 0.096 msec (Continued deformation)




t = 0.134 msec (Conclusion of event)

The results of the analyses for Cases 8 and 9 show that the damage to the Target Pipe did increase over that observed for the respective base cases but to relatively different extents. For Case 9, similar to Base Case 2, no elements exceeded the strain limit of 25% and the increase in damage was minimal. Case 8 showed appreciably more damage than it's Base Case 3 counterpart in that 13 elements were deleted compared to 5 in the base case. The conclusion is that the impact of increasing the target pipe length is significantly dependent upon other key parameters such as relative pipe thickness, initial separation distances, blowdown force, etc.

## 7.0 Summary

Actual Turbine Building pipe to pipe interactions were evaluated resulting in a set of bounding interactions. Detailed Finite Element models were prepared for each of these bounding cases. The parameters for each of the bounding cases evaluated are provided in the table below.

| Case | Target Pipe, OD, in | Target Wall t, in | Projectile Pipe, OD, in | Projectile Pipe, t, in | Target Span, ft | Separation Distance, ft | Blowdown Force on Projectile Pipe | Number of Failed Elements in Model | Surface Area per Element, $in^2$ | Failed Pipe Surface Area Opening, $in^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Case 1 | 14 | 0.5 | 8.625 | 0.5 | 12.5 | 4 | F = 37,500 lbs | None | 1.22 | 0 |
| Case 2 | 14 | 0.5 | 12.75 | 0.375 | 12.5 | 4 | F = 57,000 lbs | None | 1.22 | 0 |
| Case 3 | 16 | 0.375 | 16 | 0.375 | 13.5 | 3 | F = 92,100 lbs | 5 | 1.4 | 7.00 |
| Case 4 | 16 | 0.375 | 20 | 0.375 | 13.5 | 1.333 | F = 147,000 lbs | 3 | 1.4 | 4.20 |
| Case 5 | 24 | 0.375 | 16 | 0.375 | 16 | 5 | F = 92,100 lbs | 4 | 2.09 | 8.36 |
| Case 6 | 24 | 0.375 | 20 | 0.375 | 16 | 2 | F = 147,000 lbs | 2 | 2.09 | 4.18 |

Parametric investigations were performed for a few key modeling parameters. The results show that a Target Pipe boundary condition with lower (lighter) spring constants tend to result in more damage to the Target Pipe. Physically the lower spring constants would represent a piping system with less support / less restraint.

Another parameter investigated was the length of the Target Pipe span (distance of Target Pipe Support separation). The results show that for impacts with no sustained force on the Projectile Pipe that shorter Target Pipe spans are more conservative, i.e. more resultant damage to the Target Pipe. Conversely, for impacts which include a blowdown force on the Projectile Pipe the longer Target Pipe spans result in more Target Pipe damage.

The sensitivity to each parameter variation is individual to each specific interation pair as it depends on a number of key interaction parameters such as relative thickness of the two pipes, blowdown force, initial separation of the two pipes, etc.

## 8.0 Conclusions

The results of the analyses, included in the table above, show clearly that none of the cases would produce an excessive flooding event within the Turbine Building.

## 9.0 References

The following references were reviewed and used in the generation of this calculation.


[1] EC 15656, Rev. 0 dated 3/5/2010 - "EVALUATION OF FLOODING TIMES AND FLOW RATES ASSOCIATED WITH UNIT 1 AND UNIT 2 TB FOR SIGNIFICANCE DETERMINATION"

[2] EC 16090, Rev.0, dated "In Process" - "TURBINE BUILDING FLOODING SDP: CL TURBINE BUILDING PIPE BREAK ANALYSIS

[3] US NRC Piping Fracture Mechanics Database (PIFRAC), Version 3.1, from US NRC Pipe Fracture Encyclopedia, 1997."

[4] Structural Engineering Handbook, Edwin H Gaylord, Jr. / Charles N. Gaylord, McGraw-Hill Book Co., 1968

[5] NUREG / CR-3231 PNL-5779 Pipe-to-Pipe Impact Program, May 1987

[6] Experimental Study and Numerical Simulation of Pipe-to-Pipe Impact, International Journal of Impact Engineering, May 2009

[7] Xcel Energy, NSPM Calculation No: ENG-ME-732 "Determination of HELB / Flooding Interactions in the Turbine Building", Rev. 0, 1/18/2010

[8] Machine Design Theory and Practice, Deutschman, Michels, Wilson,Macmillan Publishing Co. 1975

[9] ASME B31.1 - 1989 Edition, Power Piping

[10] Prairie Island Unit 1 Pipe Rupture Analysis Feedwater Piping System, NSC-PIP-M-SLR-9, Rev. 1, August 11, 1972

[11] Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings, and Pipe", 1988 Crane Co.